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MECHANICAL TESTING OF EPON SU-8 WITH SIEM*

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ABSTRACT

High aspect ratio structures are often present in MEMS devices and EPON SU-8 is often used to produce such structures because of its low cost. It is essential to know the mechanical properties of SU-8 for producing reliable MEMS products. However, the mechanical properties of SU-8 may depend on the manufacturing process and the size of the structure, which is in the micron domain. Hence, one needs to test specimens that are similar in size to MEMS structures to determine if the mechanical properties change with processing protocol. In this work, we applied the newly developed technique SIEM (Speckle Interferometry with Electron Microscopy) to the determination of SU-8's mechanical properties.

INTRODUCTION

With increasing demand in MEMS applications, technical challenges lies in new processes capable of fabricating a variety of materials for MEMS. Thus it is essential to understand the mechanical properties of these materials (e.g. Young's modulus, yield strength, etc.) in order to design a MEMS device intelligently and predict its life expectancy.

There are several kinds of materials that can be used in MEMS applications, such as polysilicon [1], PMMA [2] (polymethylmethacrylate) and EPON SU-8 [3]. Polysilicon thin films have been widely employed as structure materials in MEMS. They are vapor deposited, so they are by nature only a few microns thick. Thus they can not be used for high aspect ratio structures. But the presence of high aspect ratio is often a requirement for fabricating MEMS structures. LIGA is an ideal technique to manufacture such structures. LIGA makes use of x-ray lithography to pattern very thick PMMA used as templates for electroforming devices or shims for subsequent replication steps. The acronym LIGA comes from the German name for the process (Lithographie, Galvanoformung, Abformung) which uses lithography, electroplating, and moulding processes to produce microstructures. In the process a special kind of photolithography using X-rays (X-ray lithography) is used to produce patterns in very thick layers of photoresist. The resolution of LIGA can reach submicron levels because it features reduced diffraction, low resist absorption and minimal proximity effects due to the absence of scattering. However, the X-ray source (synchrotron radiation) and demanding mask technology make LIGA expensive. This limits many microsystem laboratories (research and commercial) from exploiting this process. Of course, the cost factor is less severe if very large volumes are mass-produced using low-cost replication techniques.

The process of using thick photo-resist EPON SU-8 and UV illumination is an alternative of LIGA. Due to its low-cost, it is referred to as the 'poor man's LIGA' [4]. The SU-8 is a negative, epoxy-type, near-UV photoresist based on EPON-SU-8 resin and has been developed for applications requiring high aspect ratios in very thick layers [5]. This photoresist can be structured up to 2 mm height and aspect ratio near of 20 has been obtained [6]. Although this optical-lithography-based process has lower resolution (microns to tens of microns) compared with LIGA, it still has great potential for low-cost MEMS applications since a substantial fraction of MEMS applications do not require submicron resolution [7-10]. In addition, it is well suited for acting as a mould for electroplating because of its relatively high thermal stability (T_g>200C° for the cross-linked (i.e., insulated) resist).

TECHNIQUES

Lorenz et al (1997) has tested the mechanical properties of SU-8 as bulk materials and practically no plastic domain was observed [4]. Unfortunately, these measurements are not in micro-scales. The three-dimensional MEMS structures and devices have micron feature sizes. When considering such small devices, a number of physical effects have different significance on the micro-scale compared to macro-scale. In the microdomain, gravity and inertia are no longer important, but the effects of atomic forces and surface science dominate. Therefore, one needs to test specimens that are similar in size with MEMS structures to determine if the materials have different mechanical properties. In addition, SU-8 is a polymer and its mechanical properties also may depend on the manufacturing process. Thus we need a technique that can test mechanical properties of MEMS materials with micron feature sizes from different manufacturing processes.

Several techniques have been developed to evaluate the mechanical properties in micro-scales, such as biaxial bulge tests [11], hardness tests [12], static or dynamic cantilever beam tests [13] and uniaxial tensile tests [14]. But none of these techniques measure strains directly on the specimen and these measurements are not consistent with the definitions in the ASTM standard.

In 1998, Sharp employed ISDG (Interferometric Strain/Displacement Gage) technique to measure strain directly on polysilicon thin film [1]. In this application, two gold lines are deposited onto the specimen and a laser beam is used to illuminate the gold lines. Light reflected from the edges of each line interferes to produce bright and dark fringes. By counting the fringes movement as the specimen is deformed, the strain of the specimen can be determined [15]. This method assumes that the deformation within the gold marks is uniform. But this may or may not be the case. Furthermore, this technique is a pointwise method in which the area within the gold lines is considered as a "point". Hence one cannot detect stress/strain concentration, the presence of a crack, etc, the traditional factors that influence the design of a macro-structure. It is also limited by the size of the specimen. It can test the specimen with width of 20 μm, but "it is not practical for the narrower specimens because the reflected laser intensity is too low" [1].

In this paper we applied the newly developed technique SIEM [16] (Speckle Interferometry with Electron Microscopy) to the determination of SU-8 material mechanical properties. SIEM is a tool for obtaining the material properties in microscopic level. It is able to perform the full field displacement mapping over a region of only several microns in size.

There are three procedures in SIEM technique, creating micro/nano-speckle patterns, recording and digitizing these patterns using a scanning electron microscope and analyzing speckle images by CASI (Computer Aided Speckle Interferometry). The random speckle patterns that are created on the specimen surface by vacuum vapor deposition are used as gaging devices to map the full field deformation. Via CASI, speckle patterns that are recorded before and after deformation are first segmented into a grid of subimages consisting of 32-by-32 pixels (or some other square arrays of pixels). The corresponding subimages are compared via a two-step FFT (fast Fourier transform) process to find the displacement vector. Once the displacement vectors of each and every subimage are obtained, strains are calculated using the derivatives of the displacement components.

EXPERIMENTS AND RESULTS

Uniaxial tension test is performed inside a Hitachi scanning electron microscope of model S-2460N. Figure 1 shows the experimental setup. The loading stage is specially designed for testing specimen with dimensions of microns. It can pull the specimen continuously on the order of nanometers. The cross-section of SU-8 specimen is 300μm×150μm. Figure 2 shows the speckle pattern on the surface of specimen. The speckle pattern is formed by vacuum deposition. The magnification of the image is 400× and it consists of 2048×2048 pixels. This leads to a pixel size of 0.14μm in X (horizontal) and 0.11μm in Y (vertical) directions. Since SIEM can resolve at least 0.2 pixel displacement, the sensitivity at this magnification is about 0.03μm in X and

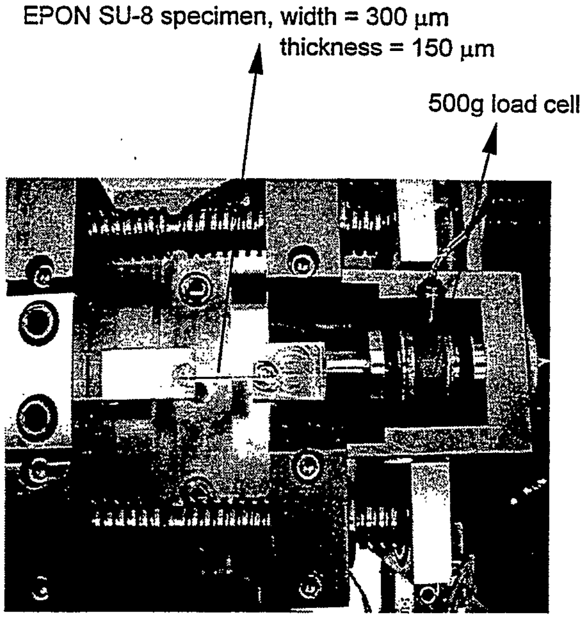

Figure 1 Experimental Setup

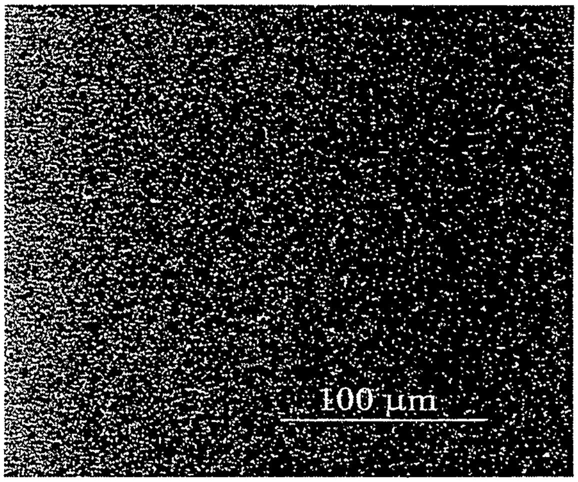

Figure 2 The speckle pattern on the surface of specimen (SEM image)

0.02μm in Y directions. Figure 3 shows v displacement field at load P=110g. It is a uniform strain field due to uniaxial tension. Strain field can be obtained by differentiating this displacement field. Once we obtain the strain-stress relationship, which is shown in Figure 4, the material mechanical properties such as Young's modulus can be determined. For this case, Young's modulus is 1.54GPa. This result can be compared with the Young's modulus of bulk material of SU-8, which is 4.02GPa [4].

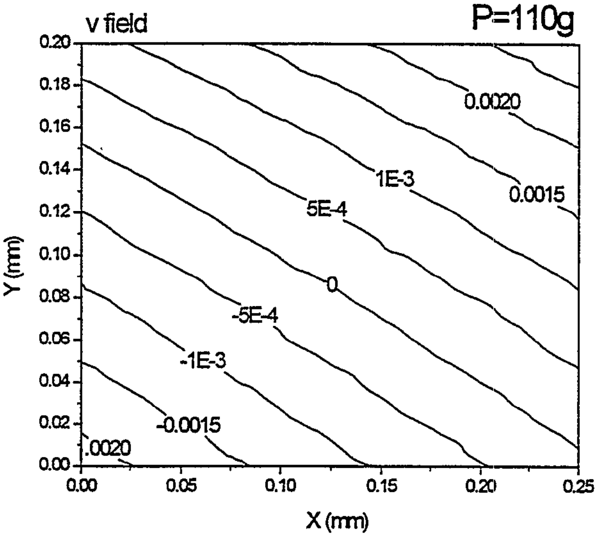

Figure 3 v displacement field at load P=110g

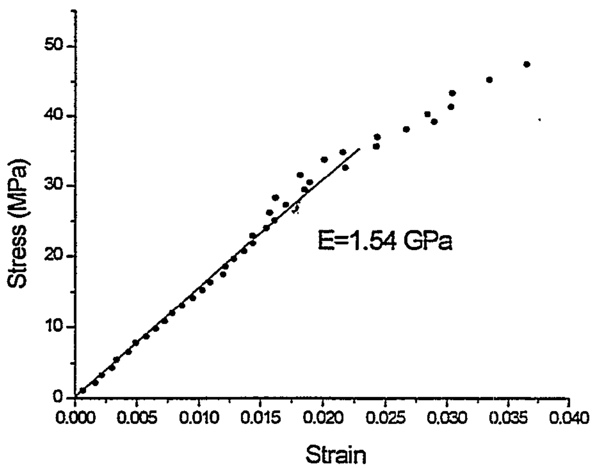

Figure 4 Stress-strain relationship of EPON SU-8
(Specimen No. 1)

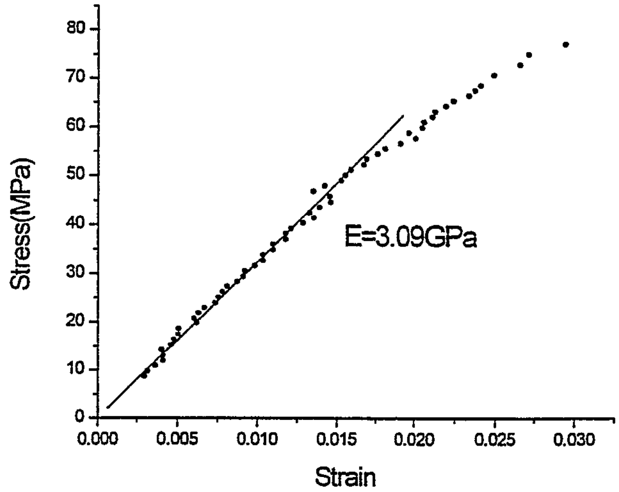

Figure 5 Stress-strain relationship of EPON SU-8
(Specimen No. 2)

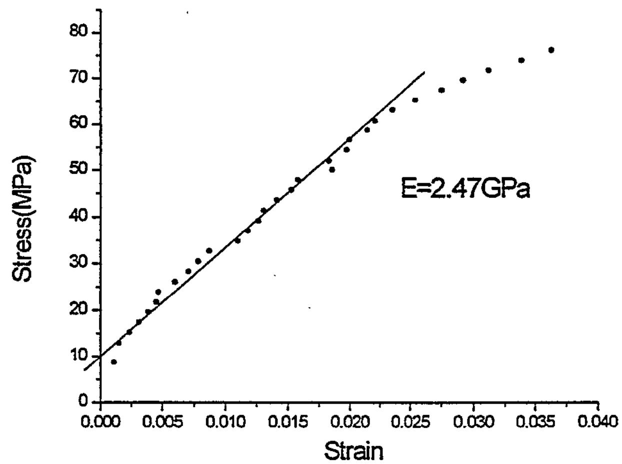

Figure 6 Stress-strain relationship of EPON SU-8
(Specimen No. 3)

The plastic deformation is clearly shown on the strain-stress relationship as depicted in Figure 4 and it was not observed by testing bulk material.

Figure 5 and Figure 6 show the results of other two tests of EPON SU-8. The cross-section of SU-8 specimens remain the same, 300μm×150μm. The only difference is that these two specimens are made from a different manufacturing process. From these results, it is clear that although the specimen size remain the same, Young's Modulus can change dramatically from 1.54 GPa to 3.09 GPa, yield strength can change from about 30 MPa to 50 MPa and ultimate strength can change from 49 MPa to 77 MPa. Thus, the mechanical properties of EPON SU-8 are truly depending on manufacturing process.

It is also noted from these figures that although the specimens No. 2 and No. 3 are from the same manufacture process and their yield strength and ultimate strength remain the same, their Young's modulus still have little difference.

CONCLUSION

Through the combination of speckle metrology, electron microscopy and digital image processing, SIEM extends the speckle technique to micromechanics domain. In this study, The Young's Modulus of EPON SU-8 was determined by SIEM. It varies from 1.54 GPa to 3.09 Gpa, indicating its dependence on the manufacturing process. Furthermore, the yield strength and ultimate strength are as a function of the manufacturing process as well.

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